Development of a Sectional Aerosol Microphysics Model and Evaluation of Aerosol/Cloud Interactions in CAM

Catherine C. Chuang
Chuanfeng Zhao
Arthur A. Mirin
Daniel J. Bergmann
Philip J. Cameron-Smith

Lawrence Livermore National Laboratory

Size-Resolved Aerosol Model with Comprehensive SOA Formation

A goal of this work is to provide a model platform to explore effects not considered in the simplified aerosol modules, which we hope will lead to improvements to the default aerosol parameterization in CAM5.

Features of LLNL CAM_Sect

Chemistry

- MOZART chemistry (200 reactions) [Emmons et al., 2009]
- SOA chemistry (10 reactions)
- 111 gas species

Aerosol microphysics

- MADRID 1 [Zhang et al., 2004]
- 224 aerosol tracers for 26 aerosol species (18 for SOAs), aerosol water and number in 8 size bins
  Na, SO_4, NH_4, NO_3, Cl, Dust, EC, POM, 14 biogenic SOAs, 4 anthropogenic SOAs

Biogenic VOC emissions

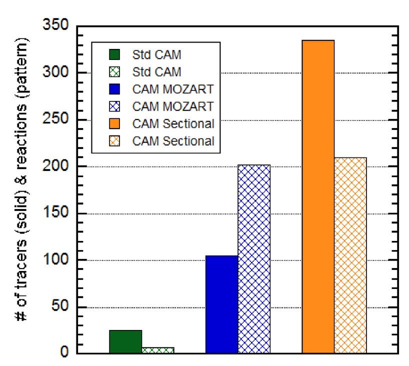
- MEGAN [Guenther et al., 2006]
- Interactive emissions of 15 VOC species from CLM
  isoprene, α-pinene, β-pinene, limonene, humulene, CO, C_2H_5OH, CH_3OH, CH_3COCH_3, CH_3CHO, CH_2O, C_2H_4, C_2H_6, C_3H_6, C_3H_8

Aerosol/cloud interactions

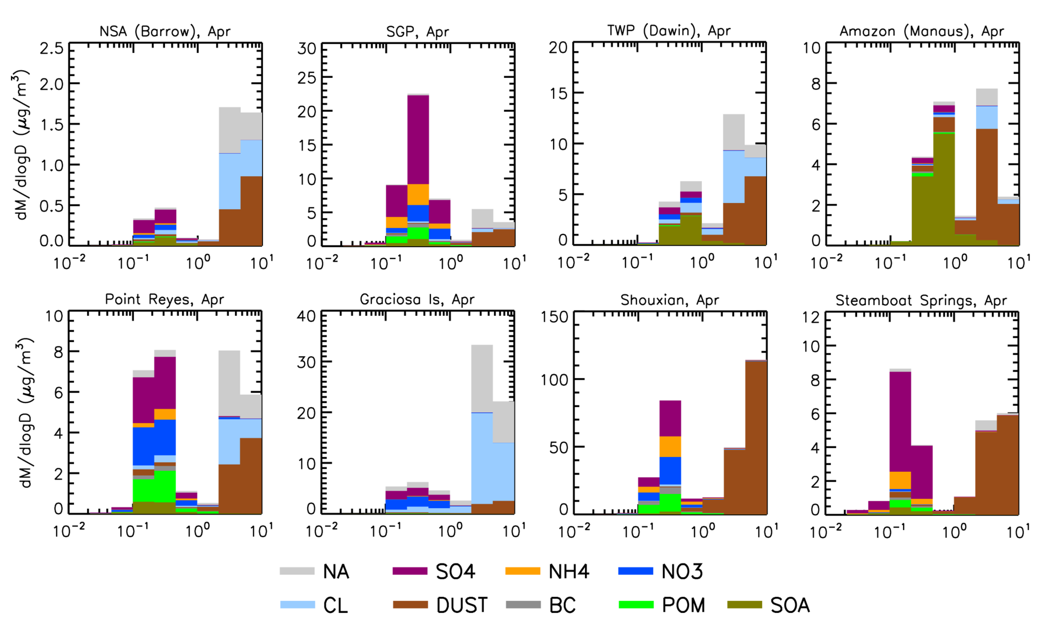
- Droplet formation dependent on size-resolved aerosol compositions

CAM_Sect uses a comprehensive treatment for the links of aerosols to their precursor gases and with the interactive biogenic sources.

CAM5_Sect contains more number of tracers (solid) and chemical reactions (pattern) than other aerosol modules in CAM.



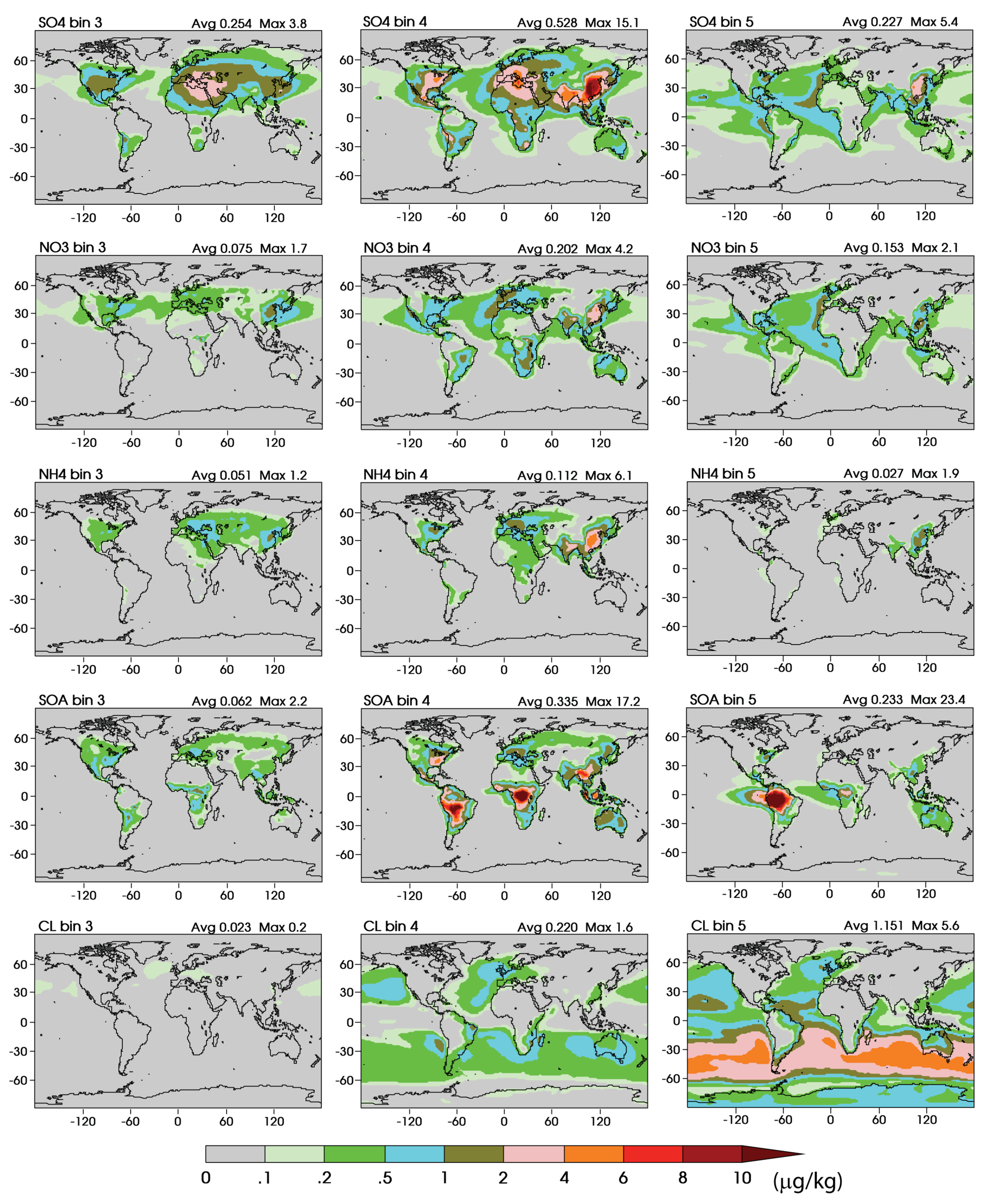
CAM_Sect presents the detailed aerosol microphysical properties important for radiation and cloud properties.



Aerosol mass concentrations and mixing simulated by CAM_Sect over the ARM sites

CAM_Sect Simulations of Detailed Aerosol Microphysical Properties

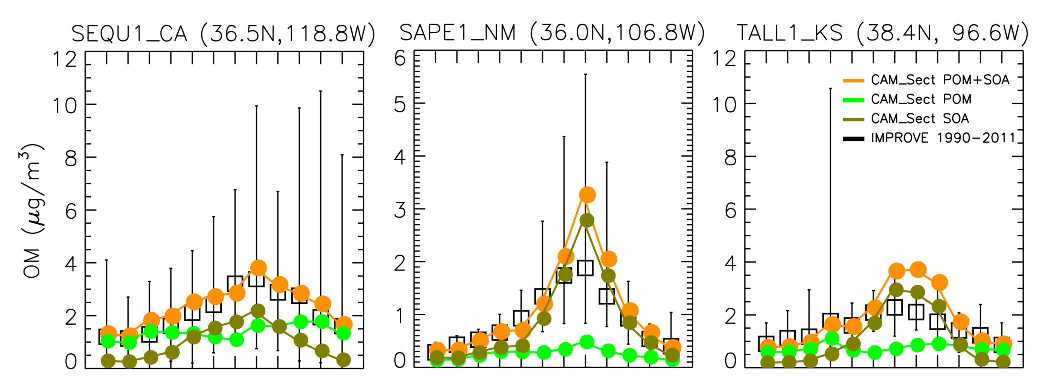
SOAs from biogenic emissions make up a significant portion of global aerosol mass concentrations.



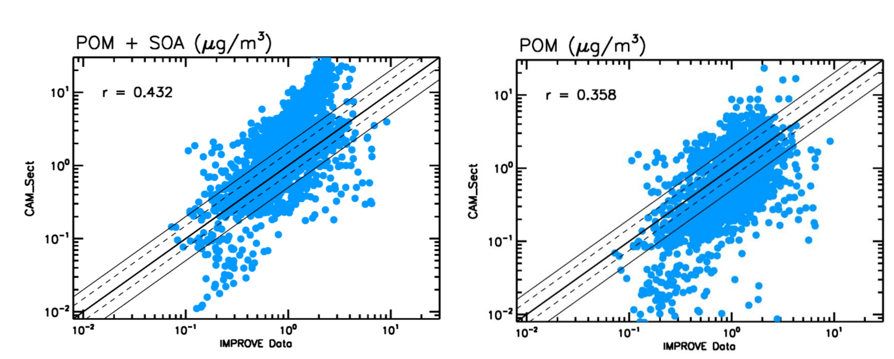
Annual sulfate, nitrate, ammonium, SOAs, and chloride at surface for size bins 3 – 5

(bin1: 0.022 - 0.046 μm, bin 2: 0.046 - 0.10, bin 3: 0.10 - 0.22, bin 4: 0.22 - 0.46, bin 5: 0.46 - 1.0, bin 6: 1.0 - 2.2, bin 7: 2.2 - 4.6, bin 8: 4.6 – 10 in diameter)

Comprehensive SOA treatment in CAM_Sect helps to reduce the bias in spatial and temporal distributions of organic particles.



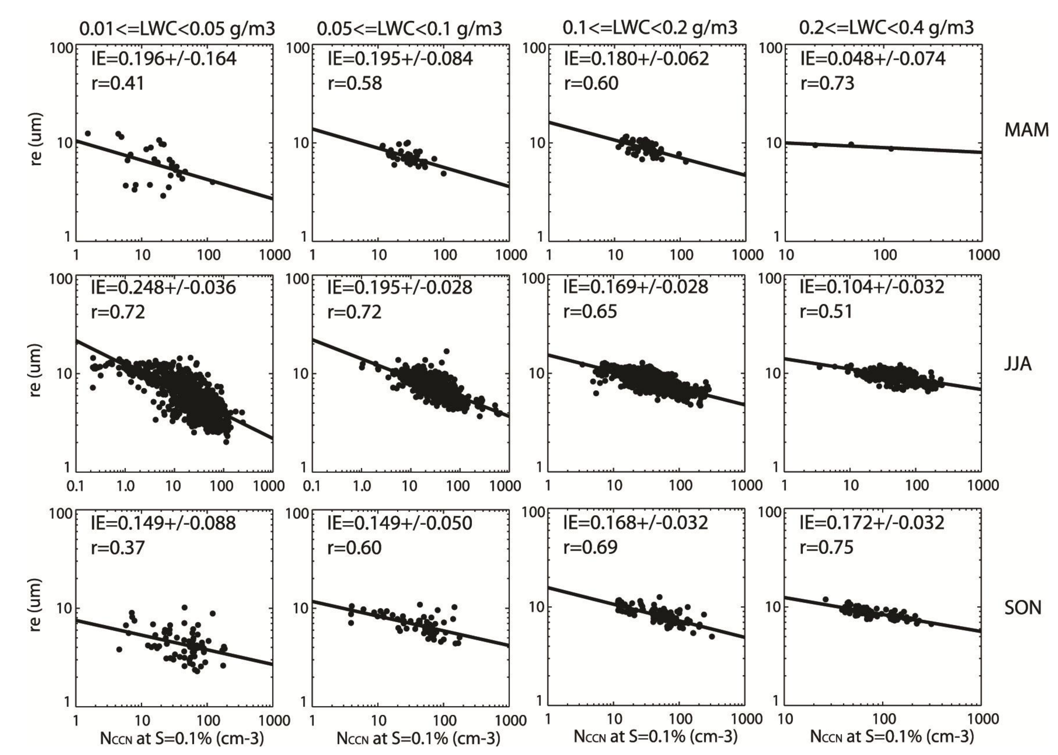
Seasonality and magnitude of OM in 3 national parks. Vertical lines represent the inter-annual range of the observed monthly mean.



Comparison of simulated OM with and without SOAs to IMPROVE data between 1990-2011

CAM Hindcasts of Aerosol/Cloud Interactions at ARM Sites

We examine the aerosol first indirect effect simulated in CAM5 at three ARM sites to evaluate the two-moment cloud microphysical scheme and its connection to aerosols.



The 1st indirect effect ($FIE = -\partial \ln r_e / \partial \ln \alpha$) from CAM5 hindcast simulations for four ranges of liquid water content at the NSA (Barrow) site. The values lie within the range (0.05 – 0.25) from observation studies for warm clouds. The clouds considered here are non-precipitating low-level single layer liquid phase clouds.

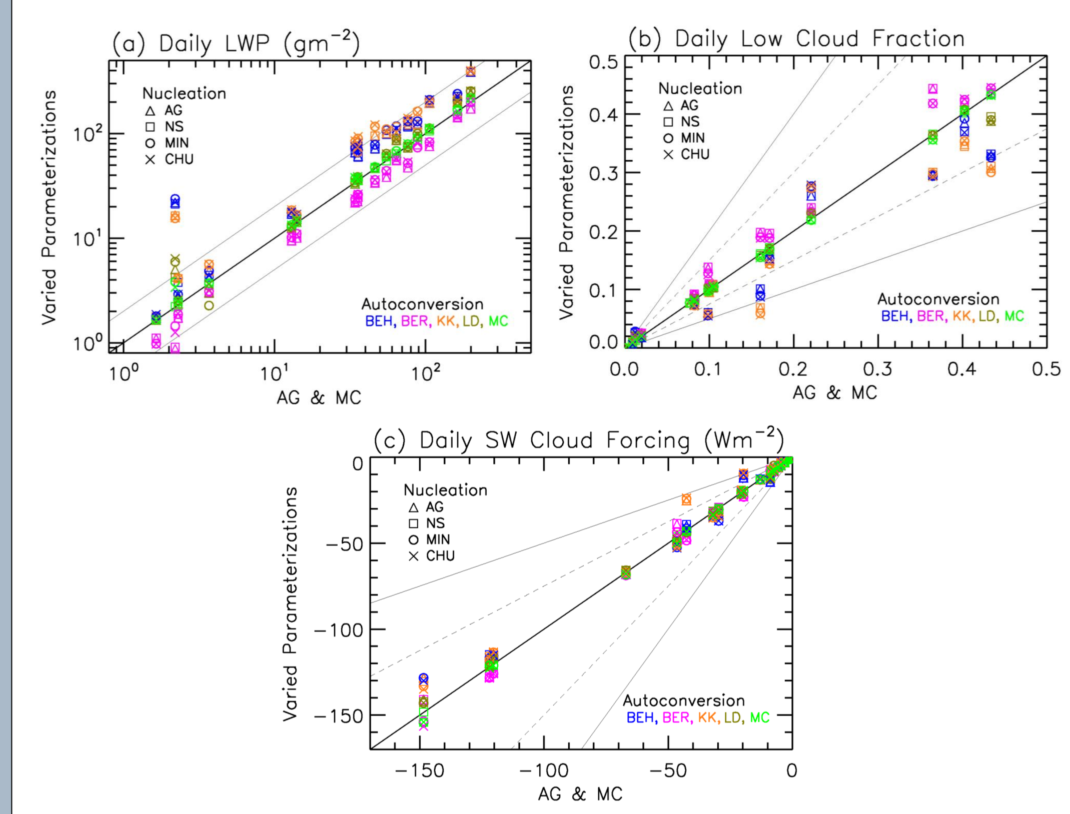
Our results suggest that if CAM5 and other GCMs over-estimate the magnitude of indirect effects, as is widely perceived, then the problem may lie in the representation of the 2nd and other indirect effects and not with the representation of the 1st indirect effect.

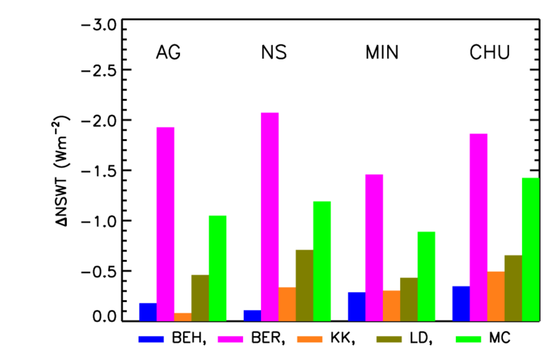
Future Works

- Compare and evaluate the simulated aerosols and cloud properties from CAM5-Sect and CAM5-MAM in AMIP type integration and CAPT framework
- Examine the sensitivity of simulated aerosol indirect effects to aerosol parameterizations and improve their performance in climate models
- Implement the coagulation module into CAM5-Sect
  -- Coagulation can be important under some polluted conditions
- Develop the parameterization of optical properties for size-resolved internally-mixed aerosols and assess the vertical profiles of simulated aerosol extinction with the ARM data
  -- Parameterize the optical properties in terms of the wet surface mode radius and the wet refractive index [Ghan and Zaveri, 2007] for each size bin

Sensitivity of Cloud Properties to Aerosol/Cloud Parameterizations

We explore the model sensitivity of CAM4 to treatments of cloud nucleation and autoconversion over the ARM SGP site during the May 2003 Aerosol IOP under the CAPT framework.





Simulated cloud properties and sulfate indirect forcing using different nucleation parameterizations and autoconversion schemes. Values in (a) - (c) are presented against the reference schemes (AG and MC).

Nucleation parameterizations
AG: Abdul-Razzak and Ghan 2002; **NS**: Nenes and Seinfeld 2003; **MIN**: Ming et al. 2006; **CHU**: Chuang et al. 2002

Autoconversion schemes
BEH: Beheng 1994; **BER**: Berry 1968; **KK**: Khairoutdinov and Kogan 2000; **LD**: Liu and Daum 2004; **MC**: Manton and Cotton 1977

In general, simulated cloud properties are more sensitive to the treatment of autoconversion than nucleation.

Calculations of sulfate indirect effects indicate that the change of shortwave fluxes from cloud lifetime effect is much more sensitive to cloud parameterizations than cloud albedo effect.

Publications

Chuang, C. C., J. T. Kelly, J. S. Boyle, and S. Xie (2012), Sensitivity of aerosol indirect effects to cloud nucleation and autoconversion parameterizations in short-range weather forecasts during the May 2003 aerosol IOP, J. Adv. Model. Earth Syst., 4, doi:10.1029/2012MS000161, in press.

Zhao, C., S. A. Klein, S. Xie, X. Liu, J. S. Boyle, and Y. Zhang (2012), Aerosol first indirect effects on non-precipitating low-level liquid cloud properties as simulated by CAM5 at ARM sites, Geophys. Res. Lett., 39, L08806, doi:10.1029/2012GL051213.

This work is supported by the Atmospheric System Research program for the Office of Science of the United States Department of Energy. This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. LLNL-POST-576594